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Data-driven sustainability evaluation of machining system: a case study

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Abstract: Improving resource efficiency and reducing waste discharge are the inevitable trend of the development of sustainable machining system. Therefore, a data-driven sustainability evaluation method of machining system is proposed. The input (energy, materials, equipment, R&D and services), and output (wastes and products) data of machining system are collected. These dimensional data are processed by emergy. The emergy flow calculation model of the machining process is established for data modeling, and the sustainability evaluation index of machining system is constructed for data analysis. Finally, an engine base machining process is taken as case study for innovative practice; and the targeted process optimization is adopted based on its sustainability evaluation for innovative practice. The feasibility and effectiveness of the method are verified. This study provides theoretical and methodological support for promoting the sustainability of the manufacturing industry.

Keywords: Data-driven; Machining process; sustainability; Evaluation

1. Introduction

Machinery manufacturing is one of the pillars of human wealth creation. However, its manufacturing process consumes a large amount of resources and generates a lot of waste, which is one of the main causes of the current global serious environmental problems [1]. The machining system is a volumetric manufacturing system, and globally the energy consumed by machine tools in machining accounts for up to 75% of the energy consumption of the manufacturing industry [2], but the energy efficiency of the machining process is low, with an average energy efficiency of less than 30% [3]. Resource consumption and environmental issues in the manufacturing industry have attracted widespread attention [4]. Therefore, how to improve the sustainability as much as possible is an urgent problem for the current manufacturing industry.

Sustainable machining has attracted the interest of many experts and scholars. Various measures and methods are adopted to improve the sustainability of machining system. For example, sustainable application possibilities for process optimization in machining using vegetable oil based Nano fluids are highlighted by Wickramasinghe [5]. A novel intelligent reasoning system to estimate energy consumption and optimize cutting parameters toward sustainable machining is presented by Xu [6]. Adaptability of AlTiN-based coated tools with green cutting technologies in sustainable machining is studied by Lai [7]. In grinding operation, sustainable application of grinding wheel waste as abrasive for abrasive water jet machining process is studied by Sabarinathan [8]. In the unconventional machining processes, Sustainability

considering impact factors and reduction methods of energy consumption is analyzed by Zheng [9]. The Environmental Performance Index reveals a strong possibility of the industrial application of Nano fluids in machining with the sustainability-based performance evaluation [10]. Regarding sustainable green cutting technology, clean cutting of titanium alloy is implemented by Nano additive-assisted minimum quantity lubrication technique [11]. Machinability under different processing conditions in sustainable manufacturing is studied and compared by Venkatesan [12]. A micro electrochemical machining sustainability assessment framework based on five dimensions of sustainability is established to justify its use and initial investment cost [13]. Energy-efficient machining is an effective way of sustainable production in current manufacturing industry [14]. Sustainable machining also has a development in unconventional machining systems [15]. Modeling and optimization of temperature and surface roughness in the milling of AISI D2 steel is studied for Sustainable machining [16]. And a novel energy model of machine-operator systems to assess the energy efficiency of machining processes is established for sustainable machining [17]. A method to improve the productivity and precision of titanium alloy parts is proposed for promoting sustainable ultra-precision manufacturing [18]. Moreover, economic and environmentally friendly methods to improve the machinability of titanium and its alloys have been proposed by Gupta [19]. These studies show that process, cost and environmental benefits of sustainable machining are the focus of attention [20, 21]. They have promoted the development and application of sustainable machining and achieved good results.

The resource consumption of machining manufacturing system is huge, which has great potential to be further explored. Therefore, the research on the evaluation of machining system oriented to sustainability is of great significance. However, machining process is a complex system, involving energy, logistics, research and development (R&D), services, equipment and waste. It is necessary to evaluate the sustainability of the whole machining system based on the unified measurement of these factors. The application of emergy theory in manufacturing enterprises [22, 23] and production systems [24] has been used for reference, and good results have been achieved. A method to evaluate the machining system is proposed and applied to the engine base machining workshop. The innovation of this study is that the relationship among energy flow, logistics and service in the system is directly displayed through emergy calculation, and the evaluation index system constructed can more accurately and truly reflect the problems existing in the machining system, which makes the optimization of sustainability targeted and feasible. It provides theoretical and methodological support for the green transformation and upgrading of machining system.

In order to reach the research objectives of this paper, the research framework is as follows. Section 2 is the method, which mainly introduces framework, emergy measurement model and sustainability evaluation indexes of the machining system. Section 3 is a case study on engine base machining system to verify the validity and feasibility of the method, and section 4 is the conclusion.

2. Method

2.1 Framework

This paper builds a data-driven method to measure, and evaluate of sustainability for machining system. Its framework is as follow:

- (i) Data collection is mainly the input and output of the machining system, data processing uses emergy to measure energy, materials, equipment, R&D, services, wastes and products.
- (ii) Date modelling is to establish an emergy flow calculation model of the machining process.
- (iii) Data analysis is based on the sustainability evaluation index of machining system.
- (iv) Innovative practice puts forward a targeted process optimization based on its sustainability evaluation.

Therefore, the method can provide support for the evaluation and optimization of sustainability for machining system, as well as support for the sustainable development of enterprises. The method framework is as follows (Fig 1):

Fig. 1 Method Framework

2.2 Data collection

The input of industrial production system involves energy, materials, equipment, R&D, and services, and the output includes waste (waste water, waste gas, waste liquid and solid waste) and products.

According to the emergy processing requirements and the input-output classification of machining system, data collection is implemented by the accounting and statistical standards. In order to facilitate calculation and evaluation, it collects the data of machining system on an annual basis. In order to reduce the uncertainty of the system, we average these data to every working day. Collection measures mainly include literature review, collection and sorting of production data, production log, dispatch list, sample collection and analysis, consultation and questionnaire of skilled workers, and data benchmarking of the same industry.

2.3 Emery measure model

The emery theory was first created in the 1980s by Odum [25], a famous American ecologist. It is a new ecological economic value theory and systems analysis method. The emery is the amount of some effective energy that is used directly and indirectly in the production of a product or service. It is basically expressed by converting all the different forms of energy in the biosphere into a solar value using a uniform scale. Since different resources, products or services have different energy values, the emery conversion rate is used to express the energy value of different categories of energy in an energy hierarchy.

The basic expression of emery analysis is:

$$EM = UEV_i \times N$$

Where, EM is emery. UEV_i is the emery conversion of different substances. N is different units of matter.

Emergy is able to quantitatively measure many types of resources, energy, products, waste and money into a single unit. It can be calculated to obtain the emergy of different input and output of machining system, so that the same unit of emergy is used to compare and evaluate.

Based on the investigation and analysis of the machining system, the energy, production materials, services and waste data of the machining processes are collected, and the Emergy measure model of the machining system is constructed.

(1) Emergy of production energy

The main energy source of machining system is electric, some of which are coal (heating), diesel (power), hydrogen (cutting), and so on.

$$E_n = \sum_{i=1}^n [N_i \times UEV(N_i)]$$

Where, E_n is the emergy of production energy in machining system. N_i is the i -th energy used in machining system. n is the total number of types of energy used in the machining system.

(2) Emergy of production materials

Production materials of machining system mainly include steel, alloys, cutting fluids, cleaning oil, water and so on.

$$E_m = \sum_{j=1}^m [M_i \times UEV(M_i)]$$

Where, E_m is the emergy of production materials in machining system. M_i is the i -th material used in machining system. m is the total number of types of materials.

(3) Emergy of equipment

It mainly includes equipment, fixture, depreciation cost, repair and maintenance cost and other equipment required by the system.

$$E_e = \sum_{i=1}^e [E_i \times UEV(E_i)]$$

Where, E_e is the emergy of equipment in machining system. E_i is the i -th equipment used in machining system. e is the total number of types of equipment.

(4) Emergy of R&D(Research and Development)

R&D mainly includes resources used for process development and improvement.

$$E_r = \sum_{i=1}^r [R_i \times UEV(R_i)]$$

Where, E_r is the emergy of R&D in machining system. R_i is the i -th resources used for process development and improvement in machining system. R is the total number of types of resources used for R&D.

(5) Emergy of production services

Production services mainly include human resources, production management, plant infrastructure and technology in machining system, which are consumed by all services to maintain the operation of machining system.

$$E_s = \sum_{i=1}^s [S_i \times UEV(S_i)]$$

Where, E_s is the emergy of production services in machining system. S_i is the i -th resources used for production services in machining system. s is the total number of types of resources used for production services.

(6) Emergy of waste

The wastes are mainly waste water, waste gas and waste residue produced in machining system.

$$E_w = \sum_{i=1}^w [W_i \times UEV(W_i)]$$

Where, E_w is the emergy of waste. W_i is the i -th waste in machining system. w is the total number of types of waste.

The emergy measurement model of machining system transforms various types of energy, materials, equipment, R & D, services and waste into emergy quantitative measurement, which provides theoretical support for the evaluation and optimization of the sustainability of machining manufacturing system.

2.5 Sustainability evaluation indexes of machining system

Before building the emergy index of machining system, it needs to clarify the emergy flow relationship of machining manufacturing system. The internal structure of machining system mainly includes equipment, R & D and service, while energy and materials are the input to the system. Of course, some of them are renewable resources and some are non-renewable resources.

(1) Net emergy yield ratio (NEYR)

Net emergy yield ratio (NEYR) is the ratio between the emergy consumed in the operation of machining system and the economic feedback emergy. Its formula is:

$$NEYR = (E_y - E_w) / (E_n + E_m + E_h + E_m + E_e + E_r)$$

NEYR is a measure of the production efficiency of a machining system. It can measure the net contribution of the machining system to economic activities and the emergy utilization efficiency. When a certain economic emergy is obtained, the higher the value of the output emergy produced, the higher the production efficiency of the system. The competitiveness of the economic activity of a system with a high NEYR value is the basic condition for the sustainable development of the machining system.

(2) Emergy yield ratio (EYR)

From the perspective of sustainable development, EYR refers to the ratio of the emergy of system output to the emergy of input. The higher its value indicates the higher productivity of the system. The more favorable it is for the development of the system. In the case of a machining system, which is different from an ecosystem, the emergy of the output of the system consists mainly of products and waste, while the emergy of inputs includes energy and materials. EYR of the machining system is:

$$EYR = (E_y - E_w) / (E_n + E_m)$$

Where, E_y is the product emergy of the machining system.

EYR is used to measure the emergy production and utilization efficiency of the machining system. The contribution of the system to the whole social and economic production activities and the utilization rate of resources can also be well measured and reflected through this indicator. This index can measure the competitiveness of system economic activities and the sustainable development index of products. The higher the value is, the stronger the competitiveness of system economic activities and the higher the sustainable development index is, which is suitable for long-term sustainable development, and vice versa.

(3) Environmental load rate (ELR)

ELR is the ratio of non-renewable resources input to renewable resources input to reflect the comparison between environmental pressure brought by the system and local environmental

carrying capacity. In consideration of the discharge of some wastes in machining system, these wastes will inevitably cause pressure on the surrounding environment. Therefore, the calculation formula of ELR is obtained as follows:

$$ELR = (N + F + E_w) / R$$

Where, R is the input of local renewable resources, N is the input of local nonrenewable resources, and F is the input of purchased resources.

The higher the ELR, the greater the pressure of the system on the surrounding environment. This indicator is the most direct indicator of the relationship between the system and the natural environment.

(4) Emergy index of sustainability (ESI)

SEI of the system is the ratio of emergy output rate and system environmental load rate. Calculation formula is

$$ESI = EYR / ELR$$

This indicator combines social, economic and ecological aspects to obtain a high-performance composite evaluation indicator. The higher the value of the system's sustainability index, the more sustainable the system is.

3 Case study

3.1 Engine base machining system

In this paper, the engine base machining system in a certain enterprise is taken as the research object. At present, this engine base belongs to mass production. The personnel, equipment, materials, methods and environment of the machining process are stable and standardized. It includes the casting, normalizing, rough processing, finishing, inspection and warehousing of rough castings. The specific steps are as follows (Fig 2):

Fig. 2 Machining process of engine base

The machining process of the engine base is a typical system, which is representative and exemplary. So we use its machining system for emergy calculation, sustainability evaluation and process optimization, and provide a new theory and method for the sustainable improvement of the mechanical manufacturing system.

3.2 Emergy accounting of machining system

The emergy calculation of the machining system of engine base mainly includes energy, materials, services, equipment and waste. The emergy system diagram is shown in Figure 3:

Fig. 3 Emergy system diagram of engine base machining system

With the help of enterprise managers and front-line employees, the data of machining workshop of engine base is collected, and the emergy flow in the machining system is shown in the table 1 and table 2.

Tab. 1 Emergy data collection table of engine base machining system

Collection object	unit	Emergy conversion rate (sej/ unit)	Reference	Collection date	Emergy (sej)
Renewable resources					
1. Solar energy	J	1	[25]	1.68E+05	1.68E+05
2. Wind energy	J	1.90E+03	[25]	9.34E+01	1.77E+05
3. Rainwater potential energy	J	3.54E+04	[25]	3.87E+01	1.37E+06
4. Rainwater chemical energy	J	2.31E+04	[25]	8.60E+00	1.99E+05
5. Geothermal energy	J	4.37E+04	[25]	3.97E+01	1.73E+06
6. Water	g	2.18E+04	[25]	6.96E+06	1.52E+11
Purchasing emergy (F)					
Casting process					
7. Sand mixing machine	CNY	8.61E+11	[23]	1.13E+03	9.74E+14
8. Spade	CNY	8.61E+11	[23]	1.17E+01	1.01E+13
9. metal mould	CNY	8.61E+11	[23]	2.48E+01	2.13E+13
10. Coated sand	CNY	8.61E+11	[23]	5.21E+00	4.49E+12
11. Molding machine	CNY	8.61E+11	[23]	6.89E+02	5.93E+14
12. Sandbox	CNY	8.61E+11	[23]	3.31E+02	2.85E+14
13. Electric furnace	CNY	8.61E+11	[22]	1.45E+02	1.25E+14
14. Iron	g	2.00E+10	[22]	6.21E+05	1.24E+16
15. Aluminum	g	5.40E+09	[22]	3.19E+05	1.73E+15
16. steel scrap	g	1.96E+10	[22]	4.48E+03	8.79E+13
17. Sandblasting machine	CNY	8.61E+11	[22]	3.06E+02	2.64E+14
18. Grinding wheel	CNY	8.61E+11	[22]	5.87E+01	5.05E+13
19. Cutter	CNY	8.61E+11	[22]	1.04E+03	8.96E+14
Normalizing process					
20. Normalizing furnace	CNY	8.61E+11	[23]	5.29E+02	4.55E+14
21. Smelting furnace	CNY	8.61E+11	[23]	4.41E+02	3.80E+14
Roughing and finishing process					
22. CK6140 CNC lathe	CNY	8.61E+11	[22]	4.98E+02	4.29E+14
23. Special machine tool	CNY	8.61E+11	[22]	2.19E+02	1.88E+14
24. Z3050 radial drilling machine	CNY	8.61E+11	[22]	4.30E+02	3.70E+14
25. Coolant	CNY	8.61E+11	[22]	1.43E+01	1.23E+13
26. Cutting fluid	CNY	8.61E+11	[22]	2.28E+01	1.96E+13
27. Cleaning fluid	CNY	8.61E+11	[22]	1.14E+01	9.81E+12
28. Clamps	CNY	8.61E+11	[23]	1.77E+01	1.52E+13
Inspection process					

29. CCD detector	CNY	8.61E+11	[23]	5.00E+01	4.31E+13
30. Quality inspection machine	CNY	8.61E+11	[23]	2.30E+01	1.98E+13

Tab. 2 Emergy data collection table of engine base machining system (continued table)

Collection object	unit	Emergy conversion rate (sej/ unit)	Reference	Collection date	Emergy (sej)
Painting packaging process					
31. Painting machine	CNY	8.61E+11	[23]	2.48E+02	2.14E+14
32. Paint	CNY	8.61E+11	[23]	9.61E+00	8.27E+12
33. Packing box	CNY	8.61E+11	[23]	1.43E+00	1.23E+12
34. Thermal power	J	2.78E+05	[23]	2.05E+08	5.71E+13
35. Protective equipment	CNY	8.61E+11	[23]	1.52E+01	1.31E+13
36. Employee salary	CNY	8.61E+11	[23]	7.07E+02	6.08E+14
37. Service information	CNY	8.61E+11	[23]	1.74E+01	1.50E+13
38. Equipment management	CNY	8.61E+11	[23]	1.88E+00	1.62E+12
39. Diesel	J	1.07E+05	[23]	3.38E+07	3.62E+12
40. Coke	J	6.44E+04	[23]	3.28E+07	2.11E+12
Waste logistics output					
Casting process					
41. Waste gas	g	7.24E+08	[24]	1.60E+01	1.16E+10
42. Waste water	g	1.29E+09	[24]	1.88E+02	2.43E+11
43. Waste residue	g	2.52E+08	[24]	1.88E+01	4.75E+09
Normalizing process					
44. Waste gas	g	7.24E+08	[24]	3.39E-01	2.46E+08
45. Waste residue	g	2.52E+08	Investigation	9.42E-01	2.37E+08
46. Waste liquid	g	1.24E+09	Investigation	1.27E+04	1.58E+13
47. Waste wate	g	1.29E+09	[24]	3.64E+05	4.69E+14
Roughing and finishing process					
48. Waste Cooling liquid	g	1.24E+09	Investigation	2.51E+05	3.12E+14
59. Waste cutting liquid	g	1.24E+09	Investigation	5.80E+04	7.19E+13
50. Waste cleaning liquid	g	1.24E+09	Investigation	1.09E+05	1.35E+14
51. Waste oil	CNY	8.61E+11	Investigation	3.41E+02	2.94E+14
53. Waste residue	g	2.52E+08	[24]	2.92E+06	7.36E+14
Painting packaging process					
52. Waste paint	CNY	8.61E+11	Investigation	4.87E+02	4.19E+14
53. Total output value in one day	CNY	8.61E+11	Investigation	6.34E+04	5.46E+16

Note: The benchmark of emergy used is 9.44×10^{24} sej / yr.

3.3 Sustainability evaluation of machining system

The emergy flow of machining system includes energy, material, R & D, equipment, service and waste. Energy is transmitted in the form of energy flow. Materials and subsidiary materials flow is transmitted in the form of material flow. R & D, equipment and services flow is transmitted in the form of money flows. Waste flows into and interacts with the ecological environment. According to table 1, the emergy flow in the machining system of the machine base is shown in Table 3:

Tab. 3 Emergy flow of machining system

Type	Emergy	Remarks
Renewable energy	3.65E+06	Wind, solar, rain, etc
Nonrenewable energy	4.16E+15	Electricity, coal, diesel, etc
Water	1.52E+11	Workshop water
Production materials	1.72E+16	Iron, aluminum, cutting fluid , etc

Equipments	5.15E+15	Machine tool, etc
R&D	5.45E+15	Process improvement and R & D
Service	1.44E+16	human resources, etc
Waste	2.8E+15	Waste water, waste gas and residue, etc
Profit	5.46E+16	Daily revenue of products

According to the above emergy calculation data, the calculation results of emergy evaluation index of engine base machining system are shown in Table 4:

Tab. 4 Emergy evaluation index

Index	Calculation results
NEYR	1.12
EYR	2.42
ELR	1.59E+05
ESI	1.52E-05

From the perspective of NEYR, the production efficiency of engine base machining system is very low, and its economic competitiveness is weak. NEYR is only 1.12. Generally speaking, the production efficiency of this machining system needs to be improved. From the perspective of energy flow, production materials and services account for a large proportion, indicating that the system is high input and low return. Its technology and R & D investment is low. It does not belong to the high-tech system.

When EYR is less than 2, it indicates that the system operation is not a sustainable production and development process, and the emergy of products is not increased due to production activities, but a process of consumption or transformation. The EYR of this machining system is 2.42. This shows that the capacity of sustainable development is weak and needs to be improved.

ELR of this machining system is 1.59E+05, which shows that a large number of nonrenewable resources are consumed in local areas (machining workshops), and the environmental pressure of this machining system is very large.

ESI of this machining system is 1.52e-05, which indicates that the machining system is not sustainable and must be improved by new processes and methods.

Based on the above evaluation, the sustainability of the engine base machining system is very weak, the environmental pressure is large, and the production efficiency is low. In the long run, this kind of processing technology needs to be improved or replaced, and clean production and green lean manufacturing need to be strengthened.

3.4 Targeted process optimization

Process optimization of engine base machining system for sustainability is determined by the above emergy evaluation indexes. In order to improve the sustainable development capability of this machining system, the following process optimization measures are taken.

(1) Optimization of casting process

Because the original process used closed pouring, it resulted in the unstable filling of molten steel and the problem that the waste liquid could not be recycled. When the closed pouring is changed to the open pouring, the flow of molten steel becomes more stable. The whole stamping process is much simpler than before, and the defect rate is greatly reduced. The liquid steel is filled from several different positions at the bottom of the casting. It greatly reduces the punching time and avoids the influence of oxide generated in a long time on the quality. For the ecological

environment, the molten steel can be recycled by flow under the pouring mode. This greatly reduces the emission of waste, especially waste liquid in the casting process, which is both economic and environmental protection. After optimization, the yield is increased by 6.1%, the riser cost of single casting is reduced by 3 CNY, the coating cost of single casting is reduced by 40 CNY, the amount of waste liquid is reduced by 3000 g / d, and the production efficiency is increased by 8.7%.

(2) Optimization of finishing process

In Table 1, we can find that the emergy of the waste in the machining system is $3.03e + 15$, which is 5.5% of the product benefit. This has a great impact on NEYR and EYR of the machining system, and directly reduces the system's ESI.

The main reason is that the proportion of cutting waste liquid and cooling waste liquid in the total waste liquid is relatively large, which leads to the increase of emergy waste rate of the system.

In order to further improve the ecological benefits, the waste discharge is needed to improve. Through the introduction of two new processing technologies, dry processing and low-temperature balanced cold air precision cutting, zero discharge of cutting and cooling waste liquid is realized.

From the perspective of emergy value, this optimization measure is worth taking, which saves emergy of $1.02e+15/d$.

(3) Reduced waste emissions

The waste gas from machining is collected by pipes and collecting covers. Then the waste gas is introduced into the low temperature plasma waste gas treatment equipment. The exhaust gas is ionized into various electrons and ions under the action of high voltage in the equipment, which has high energy and is easy to react with surrounding oxygen to generate water and carbon dioxide. At this time, the emission of waste gas is obviously controlled, and the emergy of waste is effectively reduced by $9.90E+14/d$.

Through a series of process optimization measures, in terms of economy, NEYR increased from 1.12 to 1.65. EYR increased from 2.42 to 2.67. The production efficiency of engine base machining system is increased by 13.40%. This shows that the utilization efficiency of the input emergy of the machining system is greatly improved. After optimization, the economic benefits are obviously improved. In the aspect of environment, it optimizes the material emergy of casting process, the emergy of processing process, and reduces the amount of waste. ELR decreased from $1.59e + 05$ to $1.53E + 05$, and the pressure of engine base machining system on the environment decreased significantly. In the aspect of sustainable development, with the increase of EYR and the decrease of ELR, ESI increased from $1.52e-05$ to $1.74e-05$, and its increase range is 14.2%. After optimization, the sustainable development index has a significant increase (Fig 4).

Fig 4. Effect of optimization for sustainability

3.5 Discussion

Compared with similar research results [17, 21, and 26], our research has the following advantages:

The data-driven sustainability evaluation of sustainable machining system can clearly represent the flow characteristics of machining system by data-driven. It analyzes the internal characteristics of machining system from the emergy perspective, which is different from the economic perspective. It can provide new decision-making ideas of manager form data-driven.

Secondly, the sustainability evaluation index system of machining system comprehensively considers the economic, social and environmental benefits. It reveals the internal mechanism of the sustainability of machining manufacturing system. This provides a clear path for the sustainable development of machining system.

Thirdly, sustainable manufacturing system is the inevitable trend of future development. It is an urgent need to measure, evaluate and optimize the machining system from the perspective of sustainable development in the process of green transformation and upgrading of manufacturing industry.

Last but not least, improving the ecological benefits of manufacturing enterprises is an urgent need to win the market and customers, avoid administrative punishment from the government and improve the positive image of enterprises. This is the key to enhance the sustainability of manufacturing system. This kind of optimization decision is exactly what the manufacturing enterprises are looking for.

4 Conclusion

Sustainable manufacturing system is to integrate environmental values and social responsibility into the enterprise value system, which is the embodiment of sustainable development of human society in modern manufacturing industry.

In this paper, data-driven is applied to evaluate sustainability of machining system. Its main innovations are as follows: based on the data collection of the input and output of machining system, the energy, production materials, services and waste of the machining system is analyzed by the perspective of emergy, which solves the problem of different units of measurement. The evaluation index system is established for data modeling, which includes NEYR, EYR, ELR and ESI. Through the data analysis and evaluation of the machining system of engine base, the measures

optimization of casting process, optimization of finishing process and reducing waste emissions are taken. Its effect is obvious, waste discharge is reduced, production efficiency is improved, environmental load rate is reduced, and sustainable development capacity is enhanced.

This study has a good reference for the green transformation and upgrading of manufacturing enterprises, and can provide effective solutions for decision makers. In the future, the data-driven based on emergy evaluation theory to the whole process of mechanical production will further be applied. This is significant for the development of sustainable manufacturing.

Ethical Approval

There is no potential conflicts of interest

There is no research involving Human Participants and/or Animals.

Consent to Participate

All authors and their units were informed and agreed.

Consent to Publish

All the authors agreed to publish.

Authors Contributions

Cuixia Zhang and Cui Wang contributed to the conception of the study;

Conghu Liu and Guang Zhu performed the experiment;

Conghu Liu and Wenyi Li contributed significantly to analysis and manuscript preparation;

Cuixia Zhang and Cui Wang performed the data analyses and wrote the manuscript;

Mengdi Gao and Wenyi Li helped perform the analysis with constructive discussions.

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Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Availability of data and materials

The data and materials have been included in the case study of this paper.

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